[0033] A point source microscope (PSM) 28 in accordance with the present invention, utilizing a Shack cube 30 is shown in FIGS. 3A-3B. A Shack cube 30 is a beam splitter cube 30a to which has been attached an uncoated plano-convex lens 30b; the convex surface of lens 30b is sometimes called a Shack surface. While a cube has, of course, six faces, two are unused in the Shack cube. The four remaining surfaces are referred to herein as being "optically functional", since one or more of these surfaces is employed in the practice of the present invention.

[0034] Typically, as shown in FIG. 3a, the convex surface of lens 30b used in making a Shack cube 30 has a radius-of-curvature that is equal to the total thickness of the lens and the beam splitter cube 30b. This makes building a Shack cube interferometer convenient, since a pinhole aperture disc may then be placed on the cube 30. However, the radius-of-curvature of the lens 30b may be less than or more than the total thickness. In the preferred embodiment, as shown in FIG. 3b, the lens radius-of-curvature is large enough so that the point source 20 is conveniently located outside of the cube 30. Moving the point source 20 away from the beam splitter 30b provides space for a detector (e.g., CCD camera 32 shown in FIG. 3b.) behind the cube 30 to receive the focused point images from the Shack reference surface 30a and sample 24 without additional relay lenses.

[0035] The point source 20 is most typically a single-mode fiber-optic cable 12 (see, e.g., FIG. 5), but may be a multimode fiber, pinhole aperture disc in a spatial filter assembly or any of these in conjunction with an additional lens or lenses (not shown) to relay the point source. The purpose of a relay lens is to assist in packaging or to change the numerical aperture of the point source 20 used to better match the application. For example, improved precision can be obtained by using a larger numerical aperture so that the focused point of light will be smaller.

[0036] The point source 20 and Shack cube 30 may be made as an integral component of an eyepiece assembly to be used with a conventional microscope or can be made as part of a microscope tube for use with conventional eyepieces and objectives.

[0037] FIG. 4b shows the path of a light ray exiting an objective lens 26, striking a surface 24 and then being reflected back towards the objective. The light ray is representative of light from a point source in a PSM (point source module or microscope) 28.

The point image formed on the camera 32 by light striking the surface 24 will be at the same location as the point image formed by light coming from the reference surface 30b in a PSM 28. The point image so formed will vary in size as the axial distance between the objective 26 and surface 24 is varied (i.e., focus is varied). The type of reflection in FIG. 4b is commonly referred to as a cat's eye type of reflection.

[0038] For comparison, FIG. 4a is referred to herein as a retroreflection. A pair of light rays exiting the objective 26 is shown intersecting at the center of curvature of a concave surface 23. The rays strike the concave spherical surface 23 normal to the surface and are reflected back along the same path towards the objective 26. The point image formed in this case will vary in size as a result of axial displacement and will also, unlike the cat's eye type reflection, shift laterally on the detector 32 in proportion to the distance the objective 26 is displaced laterally from the center of curvature.

[0039] An alternative design for a point source microscope (PSM) 128 of the present invention is shown in FIG. 5. A compact housing 50 is made possible through the use of a revised optical design. As before, there is a point source 20 of light that is indicated as a fiber optic connector 12 in the Figure. The fundamental difference between this design and the previous design is the rotation of the Shack cube 30 so that the Shack lens 30b is not part of the test arm, which is the optical path for imaging the sample 24. Instead, light from the point source 20 is transmitted through the beam splitter 30a to a collimating lens 52 and to an objective lens 126. As a result of this design, precise transverse alignment of the point source 20 to collimating lens 52 and objective lens 126 is easily obtained. The light source 20 may be a fiber-coupled light emitting diode, laser, laser diode, or other light source permitting the use of coherent or incoherent light sources. It is also possible to use as source 20 an incandescent light bulb or light emitting diode in conjunction with a lens or lenses (not shown) and a pinhole (small aperture) (not shown).

[0040] Light from the point source 20 strikes the beam splitter 30a and the transmitted light is collimated by collimating lens 52 and brought to focus by objective lens 126 in the test arm (beam splitter 30a to sample 24) of the PSM 128. The lenses 52 and 126 may have the same or different focal lengths, providing the ability to have an output numerical aperture different than the numerical aperture of the source 20. This is

helpful, since single-mode optical fiber typically has a small numerical aperture. The small numerical aperture of a fiber 12 has a benefit in that only a small amount of spherical aberration is introduced by the beam splitter cube 30. Lenses 52 and 126 are typically glass molded aspheric elements having high wavefront quality resulting in a small spot size (typically diffraction limited) for the projected spot. If the projected point image produced by lens 126 is at or near a surface or center-of-curvature of a spherical surface, then a portion of the light reflected or scattered by the surface will form a point image on the camera 32 after reflection from the beam splitter 30a.

[0041] A portion of the light from the point source 20 is reflected by the beam splitter 30a towards the Shack reference surface 30b. Light reflected from the reference surface 30b forms a reference point image on the camera 32. The reference surface 30b may have a reflective coating to control the brightness of the reference point as well as to reduce stray light that is transmitted through the reference surface. Additionally, the Shack lens 30b may be made of a partially light absorbing material or a filter (not shown) may be placed between the Shack lens 30b and the beam splitter 30a to control stray light and to balance the relative brightness of the optical radiation from the spherical reference surface and from the sample via the objective. The reference and test images are coincident in FIG. 5 and are indicated by the intersecting lines (rays) at the camera 32.

[0042] The collimating lens 52 and objective lens 126 can be considered to be a single objective lens assembly or lens module. Additionally, it is possible to intentionally incorporate astigmatism in the objective lens 126 or collimating lens 52. The result is that the point image resulting on the detector will be circular at the optimal focus; however, either side of focus the image will appear as a short line segment. More useful, though, is that the orientation of the line segment on one side of focus will be orthogonal to the line segment on the other side of focus, thereby making it obvious which side of focus one is on as well as increasing the precision with which the optimal focus position of the PSM can be set. It is possible to do this in either PSM configuration 28 or 128.

[0043] It is useful to note that it is possible to exchange the location of the detector 32 and point source 20 in both PSM configurations 28 and 128. The PSM configuration 28 shown in FIGS. 3A and 3B is preferred and corresponds to the classical micro-